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Land-site suitability evaluation for tea, cardamom and rubber using Geo-spatial technology in Wayanad district, Kerala

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Abstract: Kerala is one of the important states contributing to the production of plantation crops and spices in the country. Soil and Land evaluation in various land utilization types has been carried out to assess the land suitability for tea, cardamom and rubber in Wayanad district of Kerala. Different soil physico-chemical parameters like, pH, electrical conductivity, organic carbon and physical attributes database of soil mapping units developed in inventorying of soil resources at 1:50K scale using LISS-III satellite data on soil series and its association used to evaluate soil site suitability for tea, cardamom and rubber. The results indicated that for tea around 55.79% area is suitable for cultivation of which 14.62 %, 25.51 % and 15.66 % found highly suitable (S1), moderately suitable (S2) and marginally suitable (S3), respectively. About 26.92 % and 12.10 % found moderately suitable (S2) and marginally suitable (S3) for cardamom and about 32.48 % area marginally suitable (S3) for rubber. The area unsuitable for cultivation (N) of tea, cardamom and rubber were found to be 11.69 %, 28.46 % and 34.99 %, respectively, due to constraints like relief, topography, soil physico-chemical attributes such as base saturation, pH and soil moisture regime etc. The study proposed an integrated methodology for mapping and assessing suitability of land using remote sensing and GIS techniques.
Keywords: Base saturation, GIS, Land suitability, Satellite data, Soil pH

INTRODUCTION

Natural soil bodies are the result of living organisms and climate acting on parent material, with topography exerting a modifying influence with time required for soil-forming processes to act. Thus, understanding the soil distribution pattern in relation to the properties of soil and their soil forming factors is very important for the prediction of soil properties. Characterization of soils is fundamental objectives of all soil studies, as it is an important tool for the soil classification, which is based on soil properties like organic carbon, pH, electrical conductivity, calcium carbonate equivalent, percent gravels, excghangeable cations, percent base saturation, exchangebale sodium percentage, cation exchange capacity, percent sand, silt and clay. Soil characterization also helps in documenting soil properties at research sites, which is essential for the successful transfer of research results to other locations (Jenny, 1980; Buol *et al*., 2003).

The suitability analysis allows identifying the limiting factor of any crop production and enables decision makers to develop a crop management system for increasing the productivity of the land. The Food and Agriculture Organization FAO defined 'The suitability is a function of crop requirements for growth and production with land characteristics recorded and mapped in their natural conditions and it measure up to what extent the qualities of land unit matches the requirements of a particular form of land use' (FAO, 1976). Acquisition of adequate information on soil and land characteristics is, thus, prerequisite to formulate a viable strategy to develop an optimal land use plan. Remote Sensing has emerged as an important tool in soil resource inventory and generation of information, which helps in evolving the optimum land use plan for sustainable development at specific scale. In earlier studies carried out by Mirajkar and Srinivasan (1975) the surface features reflected in satellite images provide enough information to delineate soil boundaries accurately.

The dynamic inter-relationship between physiography and soils is utilized for deriving soil information from satellite data (Kudrat *et al.*, 1992). The utility of soil-land resource information for proper agricultural land use was proposed by Dumanski *et al.* (1987). Naidu, *et al*. (2006). Sahu *et al.* (2014) has developed soil site suitability criteria for the major horticultural crops grown in the country for identifying the potential areas for maximizing the production and to suggest ameliorating measures for better crop management. In the present study, an attempt has been made to evaluate soils of Wayanad District, Kerala state for their suitability to tea, cardamom and rubber cultivation. For this, initially digital soil map generated to identify and classify the soil types and its spatial extent with its management using resourcesat- 1 satellite data and Arc -GIS 10.2 software.

The aim of the present study was to develop Non-spatial data i e soil, land and climate attribute data consisting of soil site characteristics, physical and chemical properties of the soil types by analyzing soil samples collected during field survey, rainfall and temperature data of the district. This non-spatial information then integrated with crop specific criteria's to evaluate suitability for each (tea, cardamom and rubber) crop. The different layers were overlaid and integrated in a GIS environment and suitability criteria was applied to resulted composite map to generate land suitability map for tea, cardamom and rubber cultivation.

MATERIALS AND METHODS

Study area: Wayanad district stands at the southern tip of the Deccan plateau. The entire area of the district is drained by Kabini River and its three tributaries (the Panamaram, Mananthavady and Kalindy rivers). It lies between North latitude 11^0 27' and 15^0 58' and East 75^0 47' and 70^0 27'. The total geographical area of the district is 2, 12,940 ha. It falls under the Agro-climatic Zone- XII (Ghat Region & West Coast Plains). Wayanad is the least populated district with a population of 817420 (District Census Handbook, 2011). It can be broadly divided into distinct geology: Charnockite, Gneiss and Schist. It has a pleasant climate with mean average rainfall of 1871 mm and mean soil temperature of 22.56 ^{0}C. The major crops include tea, coffee, cardamom, pepper and rubber. Tea is grown as an industry in large estates. Other major crops are cardamom, tea, cassava, rubber, coconut and ginger. Location map of the study area is shown in Figure 1.

Soil map:

Soil resource inventorying: The soil resource inventory generated during execution of soil resource mapping of Kerala state during 2013, using satellite data of (Resourcesat- 1) LISS III sensor used to prepare soil and land resources map. The soil map was derived by integrating morphological characteristics and laboratory analysis data of soil profile to the map unit generated by four tier mapping approach comprises of viz. land use, landscape, physiography and slope.

The methodology followed for extraction of information from satellite data is essentially of standard visual interpretation based on tone, texture, shape and size etc. Soil profiles were studied based on variations in physiographic unit, parent material type, land use/ land cover and slope map. All these maps were transferred to GIS environment, overlaid and used as a base map for field survey and soil sample collection. Soil profiles were exposed, studied for the detailed morphological characteristics of each soil profile and recorded in a standard format following the soil survey manual of AIS&LUS (1970) and FAO (1977) guidelines. Soil site information was also recorded. Horizon wise, soil samples were collected and analyzed for chemical and physical properties to incorporate the results with field observations and the soils were classified taxonomically using "Keys to Soil Taxonomy" 2011. The soil boundary was delineated based on the boundary inferred by combination of various layers representing soil forming factors that were used in the base map. The polygons representing a similar parent material, physiographic unit, slope and vegetation cover was put under same soil type which is confirmed by image characteristics and field survey.

Land evaluation: The parametric approach was used to evaluate land for its suitability as per FAO (1976) guidelines (Table: 2). This approach is based on the comparison of the qualities of different land units with the requirements of actual or potential land use. In order to develop a set of themes for evaluation and ultimately produce a suitability map for tea, cardamom and rubber requirement in terms of land qualities was used as given by Naidu *et al.,* 2006. The climate, soil and land parameters, namely temperature, rainfall, land slope, physiography, soil depth, pH and organic carbon (Rapid titration method of Walkley and Black, 1934) were taken for each soil type identified and mapped as polygons in the digitized map and an attribute table generated.

To evaluate the land suitability for crops (tea, cardamom and rubber), the parametric evaluation method proposed by Sys *et al.* (1991) was employed, using soil and land characteristics. These characteristics include environmental factors, drainage properties, soil physical and chemical properties. These are rated and used to calculate the suitability index for tea, cardamom and rubber respectively (Ci) according to the formula:

$$Ci = A*B/100*C/100*D/100*E/100*F/100$$

Where, Ci: suitability index for each orchard, A: rating of prime factor in this study viz. climatic features (rainfall and temperature), B, C, D, E and F are the properties of soil mapping units.

The parameters namely organic carbon, soil depth, pH, texture, EC, slope, and altitude were used in the analysis. First, the rating tables for each factor were prepared from physico-chemical properties of soil mapping units as given in table 1. The values of attributes for soil mapping units used to derive the suitability index and the corresponding suitability ratings for these values (usually range from 0 to 100) were made for tea, cardamom and rubber, respectively. If any property of soil map unit is highly suitable, a rating of 100 is to be assigned and if it is not suitable, a minimal rating will be assigned to that factor. In this study the soil-site suitability criteria table developed by Naidu *et al.*, 2006 were used for interim match for tea, cardamom and rubber, respectively.

In the second step, the computed values of suitability

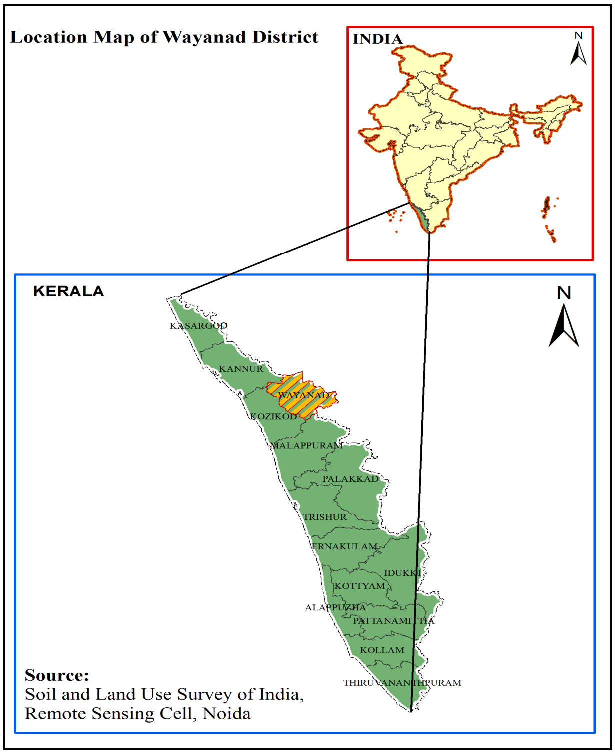

Fig. 1. *Location map of Wayanad District, Kerala.*

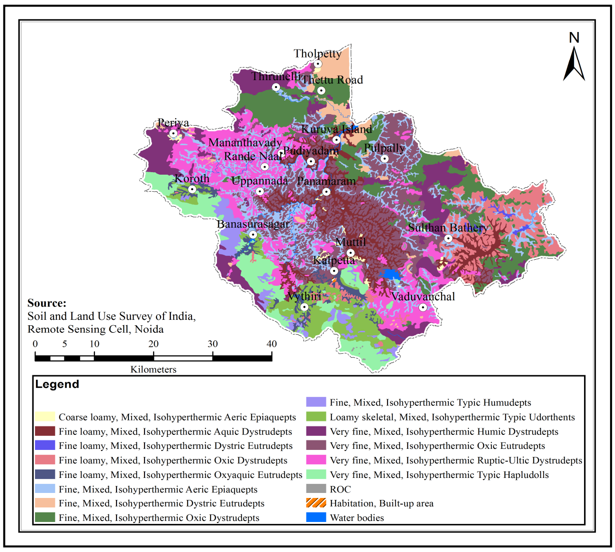

Fig. 2. *Soil family-taxonomic class map.*

index used for assessing the relative suitability for soil map unit. The suitability index divided in to four ranges as proposed by FAO (1976). The lands having indexes >75 were placed in S1 (very suitable); 75-50 were placed in S2 (moderately suitable), 25-50 were placed in S3 (marginally suitable) and map unit < 25 were placed in N (not suitable). Based on the number and the intensity of limitations, suitability classes were determined separately for tea, cardamom and rubber and crop specific suitability maps were generated.

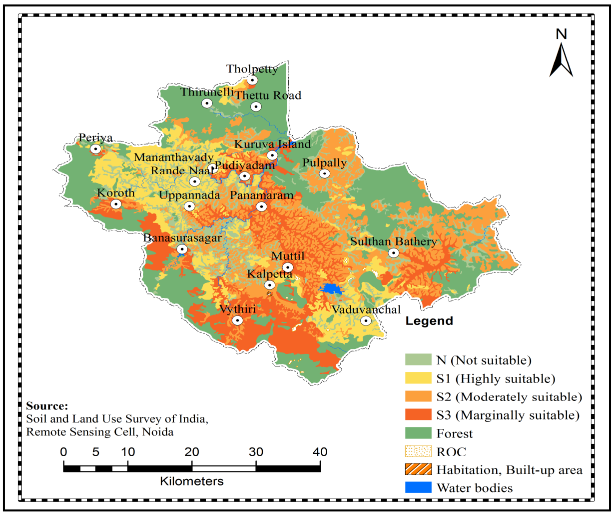

Fig. 3. *Map showing soil site suitability for tea.*

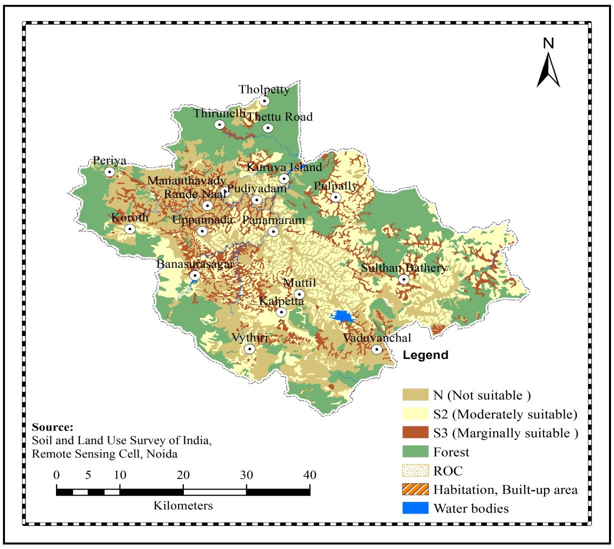

Fig. 4. *Map showing soil site suitability for cardamom.*

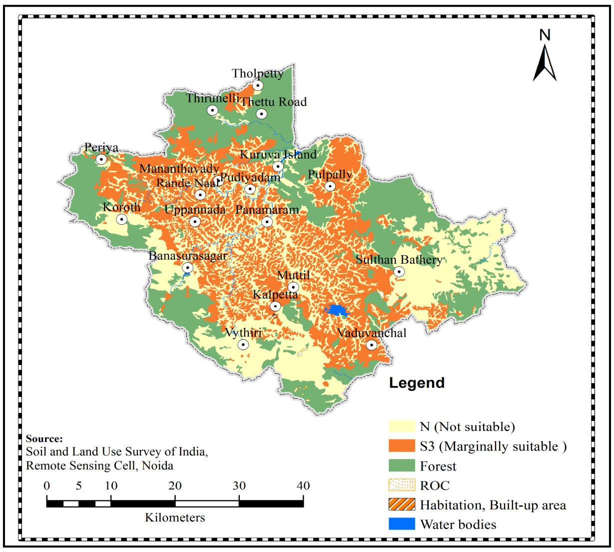

Fig. 5. *Map showing soil site suitability for rubber.*

Table 1. Distribution of area under different soil map units with their morphological and physico-chemical attributes in Wayanad district, Kerala state.

S. N.	Soil Taxonomic Class	Physiography	Geology	Land-use	Texture	pH	EC	OC	Depth	Area (ha)
1.	Fine loamy, Mixed, Isohyperthermic Oxic Dystrudepts	Hill side slopes (10-25 %)	Charnokite	Plantation	Gr. sandy clay loam	5.10	0.03	2.88	Deep	1277
2.	Loamy skeletal, Mixed, Isohyperthermic Typic Udorthents	Hill side slopes (25-50 %)	Charnokite	Plantation	Gr. sandy clay loam	4.91	0.01	0.70	Deep	10493
3.	Very fine, Mixed, Isohyperthermic Typic Hapludolls	Hill side slopes (25-50 %)	Charnokite	Forest	Gr. clay	5.31	0.03	3.80	Deep	14349
4.	Fine, Mixed, Isohyperthermic Typic Humudepts	Hill side slopes (25-50 %)	Charnokite	Openscrub	Gr. Sandy Clay Loam	5.01	0.04	3.63	Deep	5644
5.	Fine loamy, Mixed, Isohyperthermic Oxyaquic Eutrudepts	Pediment\ (3-10 %)	Charnokite	Plantation	Sandy Clay Loam	5.30	0.03	1.58	Very deep	3879
6.	Very fine, Mixed, Isohyperthermic Oxic Eutrudepts	Hill side slopes (10-25 %)	Gneiss	Plantation	Gravelly clay	6.25	0.05	2.07	Very deep	35114
7.	Fine, Mixed, Isohyperthermic Oxic Dystrudepts	Hill side slopes (10-25 %)	Gneiss	Forest	Sandy Clay Loam	5.40	0.03	2.20	Deep	18523
8.	Fine, Mixed, Isohyperthermic Oxic Dystrudepts	Hill side slopes (10-25 %)	Gneiss	Open scrub	Clay	5.14	0.03	1.23	Very deep	271
9.	Very fine, Mixed, Isohyperthermic Ruptic-Ultic Dystrudepts	Hill side slopes (25-50 %)	Gneiss	Plantation	Clay	5.50	0.08	2.58	Deep	31124
10.	Very fine, Mixed, Isohyperthermic Humic Dystrudepts	Hill side slopes (25-50 %)	Gneiss	Forest	ClayLoam	5.06	0.07	3.89	Very deep	22359
11.	Fine, Mixed, Isohyperthermic Dystric Eutrudepts	Hill side slopes (25-50 %)	Gneiss	Plantation	Gravelly clay	5.33	0.04	1.19	Deep	684
12.	Fine, Mixed, Isohyperthermic Aeric Epiaquepts	Narrow valley (1-5 %)	Gneiss	Agriculture	Sandy Clay Loam	4.90	0.06	1.15	Very deep	19651
13.	Fine, Mixed, Isohyperthermic Aeric Epiaquepts	Narrow valley (1-5 %)	Gneiss	Plantation	Sandy Clay Loam	4.90	0.06	1.15	Very deep	4563
14.	Fine loamy, Mixed, Isohyperthermic Dystric Eutrudepts	Narrow valley (1-5 %)	Gneiss	Forest	Sandy Clay Loam	5.54	0.05	1.32	Very deep	647
15.	Fine loamy, Mixed, Isohyperthermic Oxic Dystrudepts	Pediment\ (3-10 %)	Gneiss	Plantation	Sandy Loam	4.16	0.03	1.01	Very deep	12682
16.	Fine, Mixed, Isohyperthermic Dystric Eutrudepts	Pediment\ (3-10 %)	Gneiss	Forest	Sandy Clay Loam & Sandy Clay	5.56	0.05	1.90	Very deep	6676
17.	Fine loamy, Mixed, Isohyperthermic Aquic Dystrudepts	Lower Pediplain (0-3 %)	Gneiss	Agriculture	Sandy Loam	3.96	0.10	0.65	Very deep	15749
18.	Coarse loamy, Mixed, Isohyperthermic Aeric Epiaquepts	Lower Pediplain (0-3 %)	Gneiss	Plantation	Sandy Loam	4.92	0.02	0.82	Very deep	1181
19.	Fine, Mixed, Isohyperthermic Oxic Dystrudepts	Hill side slopes (25-50 %)	Schist	Plantation	Sandy Clay Loam to Sandy Clay	4.78	0.03	1.49	Very deep	985
20.	Fine, Mixed, Isohyperthermic Oxic Dystrudepts	Hill side slopes (25-50 %)	Schist	Forest	Clay Loam to Clay	4.59	0.04	2.06	Very deep	4294
21.	Fine, Mixed, Isohyperthermic Oxic Dystrudepts	Hill side slopes (25-50 %)	Schist	Open scrub	Sandy Clay Loam to Sandy Clay	4.78	0.03	1.49	Very deep	387
22.	ROC	-	-	-	-	-	-	-	-	399
23.	Habitation	-	-	-	-	-	-	-	-	161
24.	water bodies	-	-	-	-	-	-	-	-	1848
GRAND TOTAL										212940

EC: Electrical Conductivity (dS m^{-1}), OC: Organic Carbon (%)

Table 2. Soil requirements for tea, cardamom and rubber.

Soil characteristics class, degree of limitation and rating scale				
FAO Framework	S1	S2	S3	N1
Restriction Levels of Sys *et al.*	0	1	2	3
Parametric Evaluation of	100-75	75-50	50- 25	25-0
Restrictions Crop: Tea				
Soil-site characteristics **Climatic /land quality**				
Mean temperature in growing season (°C)	18-25	26-28 15-17	29-30 13-14	>30 <13
Mean RH in growing season (%)	>80	60-80	60-50	<50
Total rainfall (mm)	1800-2000	1600-1800	1000-1600	< 1000
Length of growing period (Days)	>240	240-180	180-150	<150
Texture (Class)	scl, l, cl, sl,	c, sicl, sic	c(ss), ls,s	
pH (1:2.5)	4.5-5.0	5.1-6.0 4.4-4.0	6.1-6.5 <4.0	>6.5
Effective soil depth (cm)	>150	100-150	50-100	<50
Salinity (EC saturation extract dS m^{-1})	Non saline	<1.0	1.0-2.0	-
Crop: Cardamom				
Soil-site characteristics **Climatic /land quality**				
Mean temperature in growing season (°C)	15-25	10-14 26-30	31-35	>35 <10
Elevation	900-1200	1200-1500 900-600	1500-2000 <600	>2000
Organic Carbon (%)	>2	1-2	0.7-1	<0.7
Slope (%)	2-5	1-2	5-15	>15
Texture (Class)	scl, sl	cl, c, sc	ls	s
pH (1:2.5)	5.2-6.0	6.1-6.5 5.1-4.8	4.7-4.5	<4.5
Effective soil depth (cm)	>80	80-60	25-60	<25

Source: Shivaprasad *et al.* (2001)

Crop: Rubber				
Soil-site characteristics **Climatic /land quality**				
Mean temperature in growing season (°C)	25-30	24-20 31-32	29-18 33-34	<18 >34
Total rainfall (mm)	>1750	1750-1500	1500-1250	<1250 >6000
Slope (%)	10-15	15-30	30-50 <10	>50
Texture (Class)	scl, l	sil, sicl	sc, c	c
pH (1:2.5)	4.5-5.5	5.6-6.5 3.5-4.4	6.6-7.3 <3.5	>7.3
Effective soil depth (cm)	>100	100-75	75-50	<50

RESULTS AND DISCUSSION

Soils: The study revealed that the study area is classified into three types of soil orders viz. Entisols, Incepisols and Mollisols based on presence and absence of diagnostic surface and subsurface horizon. The soils classified under Entisols does not show any diagnostic horizon except ochric epipedon of light colour and low organic matter content, these soils mostly occurs on erosional surfaces i.e. high sloping lands. Similarly, soils of Inceptisols exhibit cambic subsurface horizon, developed due to physical alteration and chemical transformation resulted due to action soil forming processes viz. loss, gain, translocation and transformation, whereas soils of Mollisols were having dark colour, high organic matter and base saturation value >50 percent, build of organic carbon which is mainly attributed to slow rate of decomposition at higher altitude . Maximum area is covered under Inceptisols. (Table: 1 and Figure: 2). The soil temperature regime is Iso-

Table 3. Distribution of area under suitability for tea.

S. N.	Suitability	Area (ha)	Area (%)
1.	S1	31,124	14.62
2.	S2	54, 324	25.51
3.	S3	33, 338	15.66
4.	N	24, 898	11.69
5.	ROC	399	0.20
6.	Habitation, Built-up area	161	0.10
7.	Water bodies	1848	0.90
8.	Forest	66, 848	31.39
GRAND TOTAL		2, 12940	100.00

S1: Highly Suitable, S2: Moderately Suitable, S3: Marginally Suitable, N: Not Suitable, ROC: Rock Out Crop

Table 4. Distribution of area under suitability for cardamom.

S. N.	Suitability	Area (ha)	Area (%)
1.	S2	57, 319	26.92
2.	S3	25, 762	12.10
3.	N	60, 603	28.46
4.	ROC	399	0.20
5.	Habitation, Built-up area	161	0.10
6.	Water bodies	1848	0.90
7.	Forest	66, 848	31.39
GRAND TOTAL		2, 12940	100.00

S2: Moderately suitable, S3: Marginally suitable, N: Not suitable, ROC: Rock out crop

Table 5. Distribution of area under suitability for rubber.

S. N.	Suitability	Area (ha)	Area (%)
1.	S3	69, 158	32.48
2.	N	74, 526	34.99
3.	ROC	399	0.20
4.	Habitation, Built-up area	161	0.10
5.	Water bodies	1848	0.90
6.	Forest	66, 848	31.39
GRAND TOTAL		2, 12940	100.00

S3: Marginally suitable, N: Not suitable, ROC: Rock out crop

hyperthermic and moisture regime is Udic in general.

Most of the survey area comes under Gneiss landscape (79.58 %) followed by Charnockite (16.7 %) and Schist (2.7 %). The Major area comes under steep to very steep slope class (42.1%) followed by strongly sloping to moderately steep slope class (26.1 %). Soils are very deep (75.3 %) occupying majority of the area followed by deep soils (23.6 %), imperfectly to excessively drained, acidic in reaction ranging from 4.23 to 6.01. Soil organic carbon ranges from 0.28 to 2.88 % and base saturation varies from 20.81 – 81.16 %.

Land Suitability: Plantation crops are grown mainly in the states of Kerala, Assam, Karnataka, West Bengal, Andhra Pradesh and Tamil Nadu. These are mostly grown in humid tropical conditions between 20 ºN and 20 ºS of the Equator. The average value of humidity varies from 55-100 percent and temperature ranges from 20^0 C to 32^0 C. However, coffee and tea require comparatively cooler climate The temperature around 15-25 °C with 70-95 per cent humidity is ideal (Naidu *et al.*, 2006). The geographic distribution of area under tea and coffee varies with the crop requirement. Tea is grown at high altitude followed by coffee under hill slopes. Coconut is mainly cultivated in coastal belt of east and west coast of India. The rubber cultivation is on the hilly slopes of West Bengal, Karnataka, North East, Tamil Nadu and Kerala (Nair *et al*., 1996).

It is difficult to specify the ideal climate requires for good growth, especially with regards to rainfall. Attempts have been made which may help in describing the land suitability for the following crops.

Tea: The upper limit of maximum temperature and minimum temperature appears to be 26.5 °C and 17.5 ° C, respectively. The results of the study given in Table: 3 and Figure: 3. In the present study, 55.79 % area of the district is Suitable (S) for tea. Out of the Suitable (S) area, about 14.62 % found highly suitable (S1) followed by 25.51 % area moderately suitable (S2) and 15.66 % area marginally suitable (S3) of total geographical area. This attributed mainly to climate, which is one of the major active soils forming factor which affects the crop and is considered as prime factor when land suitability valuation were carried out. This corroborates with the findings of Rao *et al.* (2009) who studied that climate variability in the high ranges of Kerala is likely to adversely affect the thermo-sensitive crops like tea, coffee and cardamom. Similarly 11.69 % is under Not Suitable (N) for tea cultivation. The area not Suitable (N) is due to the limiting soil factors like higher pH, base saturation and topographic situations like prevailing of aquic condition & narrow hill valleys which exist in part of the district. The marginally suitable (S3) areas having limitations like inherent soil depth (<100 cm), excessively drained soils in some parts, high base saturation and soil pH.

Cardamom: Cardamom is an economically high valued crop which is being cultivated in a cool and humid climate under the forest canopy. Generally, in the case of cardamom, the upper limit of maximum temperature has been reported to be 26 °C. No such trend was noticed in case of minimum temperature. However, the increase in cardamom yield noticed in minimum temperature within the boundary of 17°C and 18°C in majority of the years (Gopakumar, 2011). A trend was noticed by John (2003) who reported that the temperature in the range of 18°C to 24°C observed in the cardamom tracts of Guatemala. The Wayanad district is having around 1800 mm rainfall and temperature remains constant during all round the year in the mid twenties suited for cultivation of cardamom. Similar findings were earlier reported by Santiago (1967) who observed that an average rainfall of 1500 mm - 2500 mm is ideal for cardamom growth and development.

In the present study for suitability assessment and classification concludes that around 39.02 % of total geographical area found under Suitable (S) class as the Wayanad district which is having an altitude between 1000 to 2100 m above Mean Sea Level (MSL) suitable for cultivation of cardamom. This corroborates with the findings of Pruthi (1993) who reported that cardamom thrives at an elevation of 600-1500 m but the most productive range of elevation is from 1000 - 1800 m. The results of study presented in Table: 4 and Figure: 4. Under moderately suitable (S2) 26.92 % area, marginally suitable (S3) 12.10 % area and Not Suitable (N) 28.46 % area found under undifferentiated hill side slopes & pediments physiography.

Rubber: The natural habitat of rubber (*Heavea brasiliensis*) is rain forests of the Amazon basin, situated within 5° North and South at altitudes below 200 m. The climate of this region is an equatorial monsoon type characterized by mean monthly temperature by 25 to 28 °C, well distributed rainfall and no marked dry weather. Though it is originated in the Amazon basin, it is now predominantly grown in the tropics where an equatorial monsoon type climate prevails. Kerala accounts for 81 % of the area under rubber in the Country. The results of the study revealed that only one suitability class, i.e. marginally suitable (S3) with an area of 69158 ha area (32.48 %) reported for the rubber cultivation whereas 74,526 ha area (34.99 %) comes under not suitable (N). The results of study are presented in Table: 5 and Figure: 5.

The high oxygen demand associated with high respiration rates and the soils for rubber must be well drained. Similar findings reported by (Chandrasekhar *et al*., 1990; Vijayakumar *et al.*, 1998).

Conclusion

Geo-spatial technologies brought in availability of high resolution satellite data on real time basis, which are being exploited successfully for deriving the information on soil and land resource at district level. The technological advances in the field of remote sensing, and Geographical Information System (GIS) tools playing crucial role in optimal utilization of natural resources.

The land evaluation study was carried out by using FAO framework in GIS. The framework constitutes a kind of ecological analysis whereby land mapping units are evaluated with reference to define land utilization type which also incorporates climate and technological aspects.

The study concluded that about 56 (fifty six) percent area of the Wayanad district is highly to marginally suitable for tea. However, the suitability index value of marginally suitable areas can be brought under moderately suitable (S2) by adopting different corrective measures for improving soil pH and base saturation as per the requirement. In case of cardamom, only about 39 (thirty nine) percent is moderately to marginally suitable and the soil parameters such as organic carbon content, base saturation, pH and excessively drained soils were major limiting factors and only about 33 (thirty three)percent area is marginally suitable for rubber, which is mainly owing to low temperature that prevails in the district, soil physico-chemical properties like , base saturation, soil pH, imperfectly drained soils and altitude affecting the suitability for cultivation of rubber in the district.

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